International Journal on Advanced Science Engineering Information Technology

Vol.7 (2017) No. 1
ISSN: 2088-5334

Design Science Paradigm in the Development of Serious Game for Cognitive Rehabilitation

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***Abstract*— The use of serious games in cognitive rehabilitation would be invaluable to the rehabilitation process and provide advantages that may not be available in conventional rehabilitation. Although many recent game-based interventions for cognitive rehabilitation have been reported in the literature, not much knowledge is available on the best approach to developing usable games for individuals with cognitive disabilities. Therefore, Design Science approach was adopted to find a solution to this problem. This paper explores an existing Design Science framework and methodology, which are then combined and reduced into one single framework. This paper further examines how this framework can be used as a means to develop an artefact that can be used as a guideline in developing serious games for cognitive rehabilitation. The Design Science paradigm works well for the development of serious game for cognitive rehabilitation. This paper concludes with a discussion of the research contributions.**

***Keywords*— design science; serious games; cognitive rehabilitation**

I. INTRODUCTION

The increasing number of patients in therapy, as well as the heterogeneity of impairments, burden healthcare systems, resulting in the reduced efficacy of rehabilitation. On the other hand, traditional rehabilitation exercises are said to be boring, and thus causes patients to neglect their prescribed training. The use of serious games in cognitive rehabilitation would be invaluable to the rehabilitation process and would provide advantages that otherwise might not have been available in conventional rehabilitation [1].

Serious games can be more engaging than paper exercises, accommodate built-in reward and motivation systems instead of real world incentives as the sole motivation for completing the rehabilitation tasks [2].

Moreover, high-intensity exercises are often fraught with low compliance and adherence [3]. Therefore, when a patient focuses on the benefits of a game than its deficits, training becomes more enjoyable, motivating, and can be maintained over many trials required to stimulate plastic changes in the brain [4].

In addition, games afford a virtual medium that can be used as a safe environment that individuals with brain injury can explore at their own pace. They can be immersed in the game world and improve their abilities and knowledge without taking any risks [5]. For example, Coles, et al. [6] use computer games to teach safety knowledge to children with cognitive deficits. They conclude that knowledge acquired in the game world can be transferred to skills in the real world.

On the other hand, the most important advantage is the ability to distribute the game systems using the Internet. Therefore, they can easily reach remote areas [2]. Consequently, the human resource costs per patient treated and the treatment time decrease and home-bound patients can have easier access to the treatment [7].

Although many recent game-based interventions for cognitive rehabilitation researches have been reported in the literature [8]-[13], most of them have some shortcomings, such as:

- the use of small sample sizes;
- limited time being invested in usability and acceptance testing;
- the testing of respondents comprising of able-bodied and healthy users; and
- lack of therapist involvement, when in fact, they are one of the primary end-users of the technology.

As a result, the requirements for the design of therapeutic games are not clear. In other words, there is a lack of knowledge regarding the actual design requirements, as most

of the studies have a tendency to avoid real end-users i.e. the patients and therapists.

Furthermore, Torrente, et al. [5], argued that despite the potential of therapeutic games, there are only a small number of games that target individuals with cognitive disabilities. This shortcoming is motivated by many reasons, the most important of which is that cognitive disabilities are heterogeneous, difficult to categorize and require an individualized rehabilitation approach.

Therefore, creating games for this target audience is a challenge that requires highly specialized technical skills and is always a complex activity, involving high production cost. To date, not much knowledge is available about how to design usable and enjoyable games for individuals with cognitive disabilities. In addition, this research field is still in its infancy, lacking the appropriate understanding of factors contributing to the effectiveness of games for rehabilitation [14]. Therefore, it is important to undertake a deeper analysis of how therapeutic game designs can be fine-tuned to achieve the needs of the target group (i.e. patients and therapists).

Researchers need to follow a suitable research methodology to produce valuable research that will contribute to the existing body of knowledge. This research adopted the Design Science paradigm since this approach addresses ill-defined problems with unstable requirements or problems with complex interactions among its components [15].

A. Exploring Design Science

Design Science differs from behavioural/natural science, as it creates and assesses artefacts to serve human purposes; it aims to develop artificial objects to meet certain desired goals such as creating interventions that support human needs by exploring the usability and utility of the intervention created. On the other hand, natural science describes and explains phenomena or objects and how they behave and interact with each other [16].

Design Science research is a problem-solving research paradigm, which seeks to design artefacts as a solution to research problems. The two activities in Design Science are the construction of an artefact and the examination of how well it performs [16]. Some researchers [17], [18] assert that information technology artefacts are the only allowed outputs of Design Science research. However, according to Hevner, et al. [19], the artefacts are innovations used to "define ideas, practices, technical capabilities, and products", which are in turn used to analyse, design, and implement information systems, instead of a full-grown information system. In addition, a design artefact is classified by March and Smith [16], as a construct, model, method or an instantiation; or could also be "new properties of technical, social, and/or informational resources" [20].

A difference exists between Design Science research and routine design or software development methodology [21]. The routine design is "the application of existing knowledge to organizational problems, such as constructing a financial or marketing information system using "best practice" artefacts (i.e. constructs, models, methods, and instantiations) that already exist in the knowledge base". Design Science research, on the other hand, involves a theoretical foundation, which "addresses important unsolved problems in unique or innovative ways or solves problems in more effective or efficient ways" [19].

B. Design Science Three Cycle Framework

Recently, Design Science has been acknowledged as an equal companion to behavioural science. Hevner [22] proposed a framework consisting of three cycles, as shown in Fig. 1. These cycles include relevance cycle, design cycle, and rigor cycle.

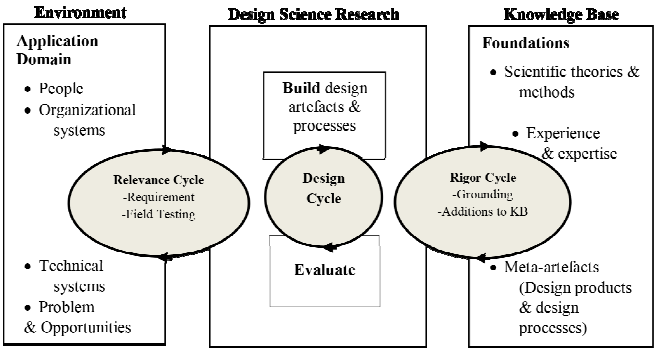

Fig. 1 Design science research cycles [22]

The relevance cycle seeks to understand the environment by determining its requirements and conducting field testing; in the design cycle, artefacts are produced and evaluated; lastly, in the rigor cycle, the evaluation of artefacts contribute to the Design Science knowledge base [22]. The design cycle is repeated iteratively until the desired artefact is achieved. During the design cycle, the requirements are gathered from the relevance cycle, whilst the theories and methods used for artefact design and evaluation are drawn from the rigor cycle.

Therefore, Design Science contributes to both the environment and its knowledge base. The environment receives a new artefact that solves the problem, and likewise, the knowledge base is expanded via any extensions to the theories and methods made during research [22].

C. Design Science Research Methodology

There is a number of literatures that provides numerous methodologies for conducting Design Science research [23-26]. These literature reveal that there is yet to be a single well-accepted methodology for conducting design science research. However, there are enough commonalities between them to enable researchers to derive their own methodology that suits their research context.

The two most cited Design Science Research Methodologies were developed by Peffers, et al. [23], and Vaishnavi and Kuechler Jr [26]. They agreed on the following common elements; the first research phase is *problem identification or awareness.* In this phase, a research problem should be stated. Furthermore, the importance of its solution should be justified.

After problem identification, the next step is to *suggest a solution and determine its objectives*. This involves understanding the nature of the problem. It also includes the available solutions (knowledge of what is possible and feasible) and explaining how a new solution is going to address the research problem.

Next, the core research phase is *design and development*. This phase consists of deciding the artefact's requirements, which, afterwards, supports the creation of the potential artefact (i.e. constructs, models, methods, and instantiations). An artefact may not necessarily be a new development [16] but it might have already been used in another domain area to solve another problem.

The next phase of research is the evaluation of an artefact, which can be done from various perspectives, such as usability, functionality, performance, quality, reliability, etc. [19]. While Vaishnavi and Kuechler Jr [26] consider evaluation as a step in the research process, Peffers, et al. [23] distinguished between demonstration and evaluation of the artefact. The demonstration shows that the implemented idea works. However, an evaluation is a formal form of assessment of how well the artefact supports the solution of the research problem [23].

The final phase of research is *conclusion* or *communication*, which may comprise of discussing the problem and its importance, the effectiveness of a novel artefact, presenting research findings and writing publications (Archer, 1984). However, if no satisfactory results are obtained, this phase also serves as a subject for further research iteration.

II. Material and Method

A. Adapting Research Framework

The framework for the Design Science Research Cycles provided by Hevner [22] lacks a defining process for conducting Design Science research. In order to address this issue, the framework and the Design Science Research Methodology (DSRM) provided by Peffers, et al. [23] are combined and reduced into one single framework, as shown in Fig. 2. The two processes (build and evaluate) of Design Science Research Cycles were replaced/expanded with a five-step DSRM process. Moreover, the reduction was also made to exclude any irrelevant parts.

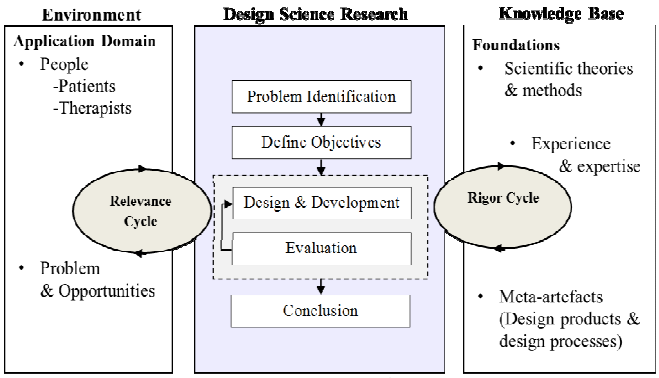

Fig. 2 Adapted research framework

B. Building A Game-based Cognitive Rehabilitation System

This research was conducted in an iterative and incremental manner using the adapted Design Science framework shown in Fig. 2, to produce an artefact as the solution to the research problem. Fig. 3 summarizes the research design and iterations, which are discussed in more detail in the following section.

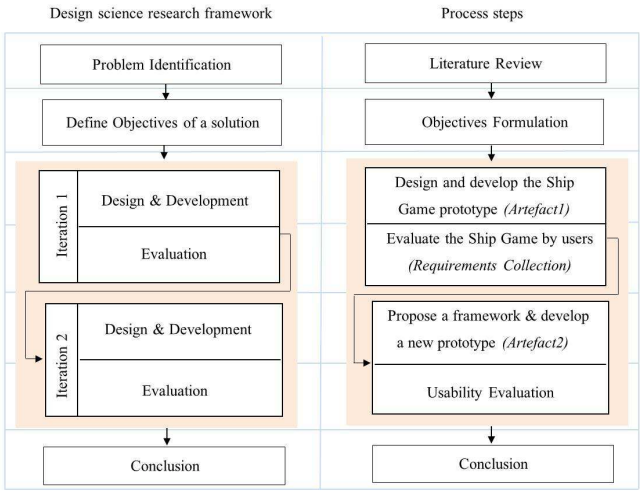

Fig. 3 The research process

1) Problem Identification:

Problem identification was achieved via a literature review, whereas the problem space and solution space were studied separately. The problem was that no systematic design and implementation method exists for developing game-based cognitive rehabilitation for acquired brain injury. The requirements for game-based cognitive rehabilitation systems were also unclear due to the lack of research related to the design and implementation of such systems.

2) Define Objectives of A Solution:

The objectives were inferred from the problem definition and knowledge of what is possible and feasible. In this research, the main objective is to develop a conceptual framework for designing a cognitive rehabilitation game that targets patients with brain injury.

The design process is a process of knowledge accumulation [26]. It is important that the design process goes through a series of iterations or cycles before the final artefact is produced. This study comprises of two research iterations, as shown in Fig. 3. Iteration one was intended to increase our understanding of the application domain, so as to determine the requirements of therapeutic games as a form of cognitive rehabilitation intervention. The new knowledge gained during this iteration would further be used for the subsequent iteration (iteration two). Therefore, in the second iteration, the main artefacts (framework) of the research would be created.

3) Iteration One

The objective of the first iteration is to understand the requirements and the potential of serious games as a form of cognitive rehabilitation intervention. This iteration consists of two phases: "design and development" and "evaluation". These phases are discussed in detail in the following sub-sections.

Design and development: Since most of the previous studies avoided the actual end users (i.e. patients and therapists), there still exists a lack of knowledge with respect to the actual requirements for the design of therapeutic games. Therefore, a game prototype was used to elicit the true requirements from actual users (i.e. patients and therapists). The game design principles were determined

from the literature. A game prototype called the "Ship Game" was then developed according to these principles, as shown in Fig. 4.

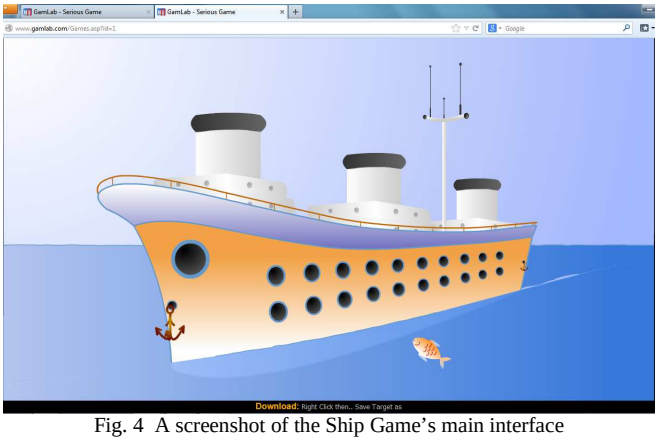

Fig. 4 A screenshot of the Ship Game's main interface

The "Ship Game" comprises of a number of mini-games. Each game targets different cognitive skills with a special focus on memory, attention, concentration, executive functions, and hand-eye coordination.

The design principles of the "Ship Game" are determined as follows:

- meaningful play, which stems from the link between a player's action and the outcome of the game, created and maintained by both the game's feedback and in handling failure positively;
- the challenge, which lies in the balance between an individual's skills and the challenges faced;
- portability, which is the system's capability to be utilized anywhere (home, hospital, or clinic); and
- interaction technology, which is the technology that the patient uses for system interaction.

The reasons behind the choice of these game design principles and the implementation details of the "Ship Game" are explained in our earlier publication [27].

Evaluation: The evaluation phase was carried out in two stages. In the first stage, the "Ship Game" was deployed at one of the Palestinian rehabilitation centres in Gaza. Twenty participants with acquired brain injury were carefully selected. The "Ship Game" was assessed and evaluated over a four-week period. During that period, the participants played the "Ship Game" for approximately one hour per session, three sessions a week. Through user testing of the game, numerous valuable lessons for designing therapeutic games that target cognitive rehabilitation were successfully identified [27].

On the other hand, and more importantly, the therapists' perceptions and their feedback were found to be indeed very critical and crucial in game-based interventions. Therefore, the objective of the second stage is to investigate the therapists' intention to use serious games for the cognitive rehabilitation of patients with acquired brain injury.

Furthermore, this stage considers the underlying factors that may affect the therapists' acceptance towards game-based cognitive intervention. In order to achieve this purpose, 41 Palestinian therapists tested the "Ship Game" through a questionnaire survey. The constructs include perceived ease of use, perceived usefulness, perceived enjoyment, and intention to use. The therapists were first asked to play the "Ship Game" for about 20 minutes.

After the session had ended, they were asked to fill in the questionnaire. In addition, semi-structured interviews regarding the survey results were also conducted with the therapists to gain an in-depth understanding of their perception and the reasons involved in their acceptance of game-based cognitive intervention. This study is described in our earlier publication [28].

According to the "Ship Game" investigation of both the patients and the therapists, the potentials and requirements for designing games for rehabilitation were identified as follows:

- the game should be playable by, and accessible to a broad range of patients;
- the game should be able to provide exercises with different levels of challenges to meet the heterogeneity of patient impairments and the increasing rate of brain-injured victims;
- the target of any rehabilitation game should be to have the least number of rules, the maximum amount of fun, and that it should handle failure in a positive way;
- the games should be made challenging;
- the games should be able to save data concerning the activities involved in playing games and present this data in a suitable way;
- the therapists should have control over the game's therapeutic activities; and
- the integration between the gaming system and the rehab centre's information system is also required.

4) Iteration Two

In the second iteration, the main artefact (a conceptual framework for designing a therapeutic game) is constructed using the findings from the first iteration. This iteration consists of two phases: "design and development" and "evaluation". These phases are discussed in detail in the following section.

Design and development: The aim of this stage is to establish a conceptual framework that can be used by game developers and practitioners when designing serious games for effective cognitive rehabilitation. In this phase, the main artefact (a conceptual framework for designing a cognitive rehabilitation game for patients with brain injury) was created, as shown in Fig. 5.

Basically, the proposed framework consists of four components, namely condition, process, activity, and outcome. Each component plays a vital role in ensuring the effectiveness of the therapeutic game produced.

In (Condition), shown in Fig. 5, the patient's assessment should be conducted by a therapist. From this, the patient's deficits, abilities, needs, and preferences are determined, and thus, realistic therapy goals can be defined. The evaluation generates information that can assist in tailoring game interventions, which further enhance the quality of training.

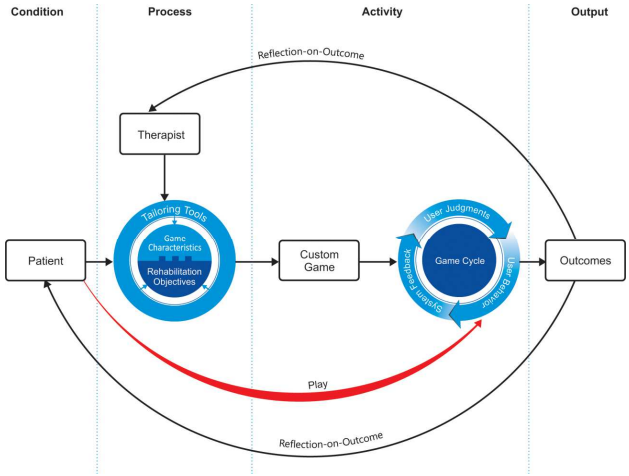

Fig. 5 A Conceptual framework for designing a cognitive rehabilitation game for patients with acquired brain injury

In (Process), as shown in Fig. 5, the therapist would now be able to use the "tailoring tools" to pair a game's characteristics with the pre-determined rehabilitation goals and hence create the appropriate therapeutic game that can fit the patients' needs.

For example, a "challenge" is a crucial game characteristic. Providing optimal challenge for a specific patient means matching the game difficulty to the patient's ability; being that it is neither too easy nor too difficult. In order to enable the optimal challenge, it is necessary to continuously adapt the game or create new game levels using "tailoring tools" to match the patient's existing skills.

Although a fully automated rehabilitation intervention which assesses the patient´s deficiencies and then uses this assessment to create an individualized rehabilitation plan is virtually possible, such intervention has low chances to be medically accepted [29]. Rehabilitation professionals' experience in formulating and determining rehabilitation objectives and selecting exercises and facilities to attain those objectives has to be recognized. However, compromising between a fully automated rehabilitation intervention and a fully therapist-dependent rehabilitation intervention is probably the best alternative [29].

In a physical rehabilitation context, environments with authoring tools that decrease time and expense enable therapists to quickly create games tailored to individuals with brain injury [30]. However, in cognitive rehabilitation, where there is diversity and heterogeneity of cognitive impairments, environments with "authoring tools" to create customizable games can be more cost-effective and can provide feasible games that can meet the specific needs of brain-injured individuals.

The complexity of a game environment depends on its "tailoring tools" and ability of these tools to map the intended rehabilitation objectives with various game characteristics based on the needs and preferences of the patient. However, rehabilitation professionals often do not possess advanced knowledge and skills to understand the underlying design and development. Therefore, the game environment and its tailoring tools should be intuitive enough without the need of much technical knowledge.

In (Activity), as shown in Fig. 5, the game is ready to be played by the patient. The retention of patient's attention and his or her deep involvement depends on the therapists' effectiveness in tailoring the game activities to their patients. If the therapist succeeds in mapping the game's characteristics with the intended rehabilitation goal in the game, this will produce a repeating game cycle. The game cycle may help sustain their patient's engagement in the rehabilitation intervention process, which in turn could lead to specific cognitive and affective outcomes.

In (Output), as shown in Fig. 5, the game play activities generate specific outcomes, which give more information on the extent of the patient's achievement when playing the game. This achievement could be as simple as an indication of the game scores such as the total amount of assets collected and the time taken to achieve the goal within the game; or it can be extended to describe the "changes in patient outcomes", which involves measuring patient improvements for a given cognitive function over time.

On the other hand, motivation and engagement in game-based training will be achieved if the patient actually believes in the potential success of game play. This perception would strengthen the patient's confidence and can be an incentive for him or her to exert more effort to attain the intended game goal. This can be reflected through outcomes that reflect his or her performance during game play. Moreover, the outcomes enable therapists to capture the changes in the patients' skills, what they are able to do, and their level of task performance and affective reactions. This proposed framework was described in an earlier publication [31].

For the purpose of demonstrating this artefact, a Rehabilitation Gaming System (RGS) prototype was developed, as a proof of concept for experimental use and evaluation, as shown in Fig. 6.

RGS is a web-based rehabilitation platform. Adobe Flash was used for creating games that can easily be viewed on the web.

Fig. 6 Rehabilitation gaming system main interface

The RGS simulates the conventional rehabilitation procedures. In conventional rehabilitation, the patient depends on the therapist's tailored plan for reducing deficits and increased participation. Therefore, the therapist has to be considered with regards to any potential technology. As a consequence, in the RGS, the therapist remains an integral part for planning (designing) game-based rehabilitation intervention.

Therefore, a user-friendly therapist-oriented game environment with "tailoring tools" is important in therapeutic game development, producing feasible games

that can cater precisely to the ability and needs of brain-damaged patients.

As shown in Fig. 7, the game design environment lets therapists create the game and save it. On the left, there are tools that can be used by therapists to build and tailor the game within the field on the right. With patient assessment, it is possible to "prescribe" training that targets specific cognitive functions.

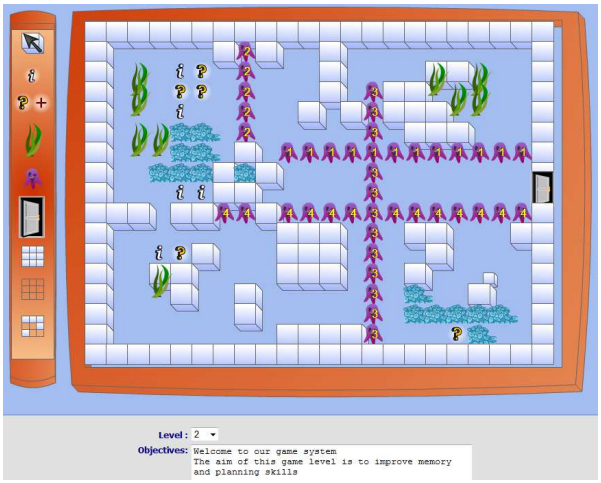

Fig. 7 Screenshot of game level design by therapist

Therapists, based on their patient's abilities, limitations, and preferences, create this game training. They can access the RGS design environment and start the design process by using the tailoring tools, drawing the Maze's pathway, adding the game's objects, identifying the behavior of the opponents, such as how they move or react during game play and by editing and adding questions to the playing field. At the bottom part of the game design environment, there is a text box, and a save button. Therapists can enter texts in the text box describing the objectives of the game, and the instructions on how to play the game. When patients log in to RGS to play the assigned game, these texts will be launched as a game introductory. In the end, after the therapist completes the design, he/she can simply click on the button marked "save" and the final result will be saved.

Design considerations and prototype development were explored in our earlier work [32].

Evaluation: Usability testing will be conducted to evaluate the RGS - by testing it with therapists. The purpose of this testing is to determine any usability problems, collect quantitative data on therapists' performance and identify their satisfaction with the RGS. We plan to conduct a usability evaluation using a usability questionnaire to rate user satisfaction with the developed system.

According to Turner, et al. [33], five users are usually enough for usability testing, because after the fifth user, the testing will repeat the same findings. Hence, five therapists will be used to inspect the RGS usability issues and rate their satisfaction with the RGS prototype.

The usability questionnaire consisted of five constructs i.e. Design/layout, Ease to use, Easy to learn, Usefulness, and Satisfaction. The items of these constructs were adapted from previously validated instruments. The therapists will be asked to examine how the tasks are performed on the RGS and to record any usability problems that they may observe. The questionnaire will be given to participants who will rate the usability issues on a seven-point Likert scale.

III. Results and Discussion

The work presented in this paper addresses a research gap in the area of serious game design for cognitive rehabilitation with the overall research goals of (a) understanding how serious games can support cognitive rehabilitation and (b) proposing a framework for the design of game activities for the cognitive rehabilitation of patients with acquired brain injury. This framework could serve as a useful guide for game developers and other practitioners in designing effective therapeutic games that can significantly and positively affect patients, therapists, and health care systems. The research was framed by an interdisciplinary setting, following the Design Science paradigm research methodology, conducted via an iterative process.

This study is composed of two research iterations. The first iteration was aimed at enhancing our understanding of the application domain and to determine the requirements of therapeutic games, whereas, in the second iteration, the main artefact was created.

The use of Design-Science research in the context of this study is relatively new. This current research analysis and synthesis could be added to the understanding of this important paradigm. In general, the research community recognizes Design Science research as a paradigm, and not as a research methodology. In other words, although Design Science research offers a new philosophy of doing research, it does not provide precise methods for conducting this research. In this study, the contribution to methodology relies on the use of the Design Science research paradigm in a novel manner. [Hevner [22]] suggests a conceptual framework to demonstrate the processes inside and around a Design Science research. This framework includes three cycles: relevance cycle, design cycle, and rigor cycle. The design cycle of this framework is only defined through the build-and-evaluate processes. Therefore, in this study, these processes (i.e. build and evaluate) are decomposed into more manageable activities.

Another important issue is that, although this study follows a Design-Science research, the key research methods used for this study (e.g. literature analysis, questionnaire, and semi-structured interviews) would normally be used for behavioural/natural science research. These research methods are aimed at constructing the knowledge base required for developing the desired artefact; the implication being that the research methods used in conventional behavioural research can be used for Design-Science research albeit with different rationales and approaches.

Additionally, this research extends the current research and advances the body of knowledge towards systemizing the design process of game-based rehabilitation. This is achieved through investigating the perception of the patients and therapists and identifying the missing factors that support the process of designing a fruitful game experience for cognitive rehabilitation. This investigation provides the vocabulary for the field of game-based rehabilitation, as well as foundational practices for the design of therapeutic games. This study also creates useful practical knowledge through

the development of a usable and innovative conceptual framework to guide the structuring and creation of game-based rehabilitation environments that are engaging and motivating to the patient, whilst addressing rehabilitation challenges.

IV. Conclusions

Design Science is used in this research to investigate how therapeutic games for cognitive rehabilitation can be designed to meet various rehabilitation needs, and create an innovative artefact (a conceptual framework for designing brain injury cognitive rehabilitation game) as guidance that would help in the development of an effective therapeutic game. In addition, for the purpose of demonstrating this artefact, a Rehabilitation Gaming System (RGS) prototype was developed as a proof of concept for experimental use and evaluation.

In the near future, usability testing will be conducted with therapists, to evaluate the RGS.

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